Gamma-Ray Line Observations of the 2000 July 14 Flare and SEP Impact on the Earth

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May 15,2001

Abstract. The HXS and GRS detectors on Yohkoh observed the 2000 July 14, X5.7 flare, beginning at $\sim$ 10:20 UT, $\sim$ 4 m before the peak in soft X rays. The hard X rays and γ rays peaked $\sim$3 m later at $\sim$10:27 UT. Solar γ-ray emission lasted until $\sim$10:40 UT. Impact of high-energy ions at the Sun is revealed by the γ-ray lines from neutron capture, annihilation radiation and de-excitation that are visible above the bremsstrahlung continuum. From measurement of these lines we find that the flare-averaged spectrum of accelerated protons is consistent with a power law $\geq$10 MeV with index 3.14 $\pm$ 0.15 and flux 1.1 $\times 10^{32}$ MeV^{-1} at 10 MeV. We estimate that there were $\sim$1.5 $\times 10^{30}$ erg in accelerated ions if the power law extended without a break down to 1 MeV; this is about 1% of the energy in electrons >20 keV from measurements of the hard X rays. We find no evidence for spectral hardening in the hard X rays that has been suggested as a predictor for the occurrence of solar energetic particle (SEP) events. This was the third largest proton event above 10 MeV since 1976. The GRS and HXS also observed γ-ray lines and continuum produced by the impact of SEP on the Earth's atmosphere beginning about 13 UT on July 14. These measurements show that the SEP spectrum softened considerably over the next 24 hours. We compare these measurements with proton measurements in space.

Keywords: flares; proton acceleration; hard X rays; γ rays; solar energetic particles; terrestrial radiation

1. Introduction

The GOES X5.7 class solar flare at 10 hr UT on 2000 July 14 from NOAA region 9077 at N17E01 was associated with a high speed halo coronal mass ejection (CME) and the largest solar energetic particle (SEP) event >10 MeV at Earth since 1991 March 29. In this paper we describe Yohkoh Wide Band Spectrometer (WBS) $\sim$50 keV to 10 MeV observations of gamma radiation both from the solar flare and from

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
15 MAY 2001		**00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Gamma-Ray Line Observations of the 2000 July 14 Flare and SEP Impact on the Earth**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,E. O. Hulburt Center for Space Research,4555 Overlook Avenue, SW,Washington,DC,20375**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

2001, Solar Physics, 204: p. 43.

14. ABSTRACT

The HXS and GRS detectors on Yohkoh observed the 2000 July 14 X5.7 flare, beginning at ∼ 10:20 UT, ∼ 4 m before the peak in soft X rays. The hard X rays and γ rays peaked ∼3 m later at ∼10:27 UT. Solar γ-ray emission lasted until ∼10:40 UT. Impact of high-energy ions at the Sun is revealed by the γ-ray lines from neutron capture, annihilation radiation and de-excitation that are visible above the bremsstrahlung continuum. From measurement of these lines we find that the flareaveraged spectrum of accelerated protons is consistent with a power law ≥10 MeV with index 3.14 ? 0.15 and flux 1.1 ?1032 MeV −1 at 10 MeV. We estimate that there were ∼1.5 ?1030 erg in accelerated ions if the power law extended without a break down to 1 MeV; this is about 1% of the energy in electrons >20 keV from measurements of the hard X rays. We find no evidence for spectral hardening in the hard X rays that has been suggested as a predictor for the occurrence of solar energetic particle (SEP) events. This was the third largest proton event above 10 MeV since 1976. The GRS and HXS also observed γ-ray lines and continuum produced by the impact of SEP on the Earth?s atmosphere beginning about 13 UT on July 14. These measurements show that the SEP spectrum softened considerably over the next 24 hours. We compare these measurements with proton measurements in space.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**14**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

the Earth's atmosphere on the following day during impact of the solar energetic particles.

Yoshimori, et al. (1991) describe the WBS in detail. The hard X-ray spectrometer (HXS) consists of a 7.6 cm (diam.) by 2.5 cm (thick) NaI scintillator coupled to a photomultiplier tube. At the time of the flare, the HXS covered the energy range from $\sim$30 to 750 keV in 32 energy channels and with 1 s time resolution. Two 7.6 cm (diam.) by 5.1 cm (thick) bismuth germanate (BGO) detectors coupled to photomulipliers make up the gamma ray spectrometer (GRS). Their gains and resolution have degraded since launch in 1991. On July 14, detector 1 covered the energy range of 550 keV to 17 MeV and detector 2 covered the range from 550 to 24 MeV, each with 128 energy channels. The temporal resolution for both detectors during the flare was 4 s.

Yohkoh has observed γ-ray spectra from other flares in solar cycles 22 and 23 (Yoshimori, et al., 1994; Yoshimori, et al., 2000). Measurement of nuclear lines provides fundamental information on the spectra of accelerated particles and the composition of the ambient medium where they interact (Ramaty, 1986; Ramaty, et al., 1995).

The earth's atmosphere also emits nuclear line radiation from impact of cosmic radiation and solar energetic particles. Share & Murphy (2001) analyzed data from the Solar Maximum Mission gamma-ray spectrometer during the 1989 October 20 intense solar energetic particle event and found 20 resolved nuclear line features. They also discussed how comparison of the intensities in some of these lines can be used to infer the spectrum of the incident protons.

In this paper we discuss hard X-ray and gamma-ray measurements of the flare beginning during the rise in soft X-rays. These include measurements of nuclear lines and the electron bremsstrahlung continuum. This enables us to estimate the time integrated spectra of accelerated ions and electrons and how the flare energy is shared among them. Because this event was associated with an intense solar energetic particle event at Earth, we also study the temporal variation of the hard X-rays to confirm the suggestion that spectral hardening may be a predictor of such events (Kiplinger, 1995). We then discuss observations of gamma-radiation from the Earth's atmosphere that was produced by the impact of these solar energetic particles.

2. Flare Observations

Soft X-ray emission from the flare measured by GOES commenced at about 10:05 UT and rose to a peak at about 10:24 UT. We display this time profile in Figure 1 where we also plot the radiation observed

by Yohkoh in hard X-rays and in two gamma-ray bands. The plotted HXS and GRS data have not been corrected for background. At the start of the observation, just after the satellite emerged into sunlight, Yohkoh was at it most southerly portion of the orbit where the cosmic ray induced background was highest. Thus the gradual fall in rate with time may in part be due to the background. The hard X-rays exhibit considerable structure with a precursor about 300 seconds prior to the main peak. The peak of the flare was observed into the nuclear γ-ray energy range as shown in the 4 to 7 MeV band. The 2.0 - 2.4 MeV band covers the strong 2.223 MeV neutron capture line and exhibits the $\sim$100 sec exponential decay characteristic of that radiation.

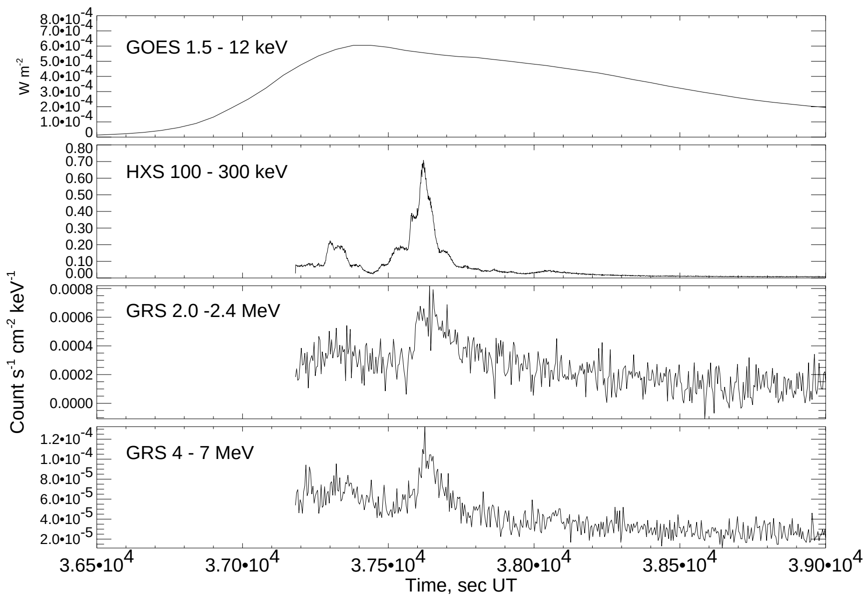

Figure 1. Time history of the 2000 July 14 flare observed by GOES and the Yohkoh WBS.

In order to obtain the most reliable temporal and spectroscopic information, it is important to correct for the varying backgrounds in both the GRS and HXS data. For flares with durations greater than $\sim$100 s, the best method utilizes data taken both 15 orbits before and after the flare, when the orbital tracks of the satellite are similar. As we discuss below, the radiation environment on July 15 was significantly elevated at high latitudes from the impact of solar energetic particles. For this reason we were only able to use data from July 13 (shifted in time by about ~ -500 s from the flare) to make the background correction. As there were no data on July 13 that could be used for the first $\sim$80 s of the flare, we used data taken on July 16 with a

time dependent correction factor determined by a comparison with overlapping July 13 data.

2.1. Flare spectra

We created background subtracted HXS and GRS (detector 1) spectra for the major part of the flare (37265 - 38300 s UT) and for four individual sections covering: 1) the short period before the first peak (37182 - 37265 s); 2) the first peak (37265 - 37460 s); 3) the primary peak (37460 - 37800 s); and 4) the decay phase (37800 - 38300 s). We plot these count spectra in Figure 2. The spectral points are plotted on the same scale, after being divided by the geometric areas of the detectors. Because these are not actual photon spectra, we do not expect the hard X-ray and gamma-ray spectra to merge.

We first detect evidence for nuclear line emission during the first peak. Both the 511 keV annihilation line in the HXS and the 2.223 neutron capture line in the GRS are detected from the first peak through the decay phase. In addition, we note the characteristic fall-off in rate $\gtrsim$ 7 MeV where the nuclear line contribution ends. The gains of both the HXS and GRS have changed from the last calibration in 1997. The annihilation line appears at an energy of $\sim$475 keV, consistent with the location of the background line in the HXS. The neutron capture line appears at an energy of $\sim$2315 keV; this is also consistent with a shift to higher energy observed in the background lines.

The solid lines represent fits to the data using a forward-folding technique. For the hard X-ray region we fit the spectra from 80 to 600 keV with either a single or broken power law and a line at 511 keV. For the GRS spectrum we fit the spectrum with a single power law, and ten narrow and five broad nuclear lines, with energies and widths determined from measurements made with the SMM spectrometer (Share & Murphy, 1995; Share & Murphy, 2000). Because of the presence of these overlapping broad lines from heavy ion interactions on ambient H, the energy resolution of the GRS is not sufficient to permit the narrow lines to be reliably separated, with the exception of the neutron capture line at 2.223 MeV. We therefore display only the overall fits to the data. This lack of sufficient spectral resolution prevents us from determining the prompt O/Ne (6.13 MeV/1.63 MeV) line ratio that can be used to measure the temporal evolution of the accelerated particle spectrum (Ramaty, et al., 1995).

We can still obtain a flare-averaged measurement of the accelerated particle spectrum by using the integrated fluences in the 2.223 neutron capture line and in the total nuclear contribution to the 4 – 7 MeV band (Ramaty, 1986). We plot the flare-integrated count spectra from

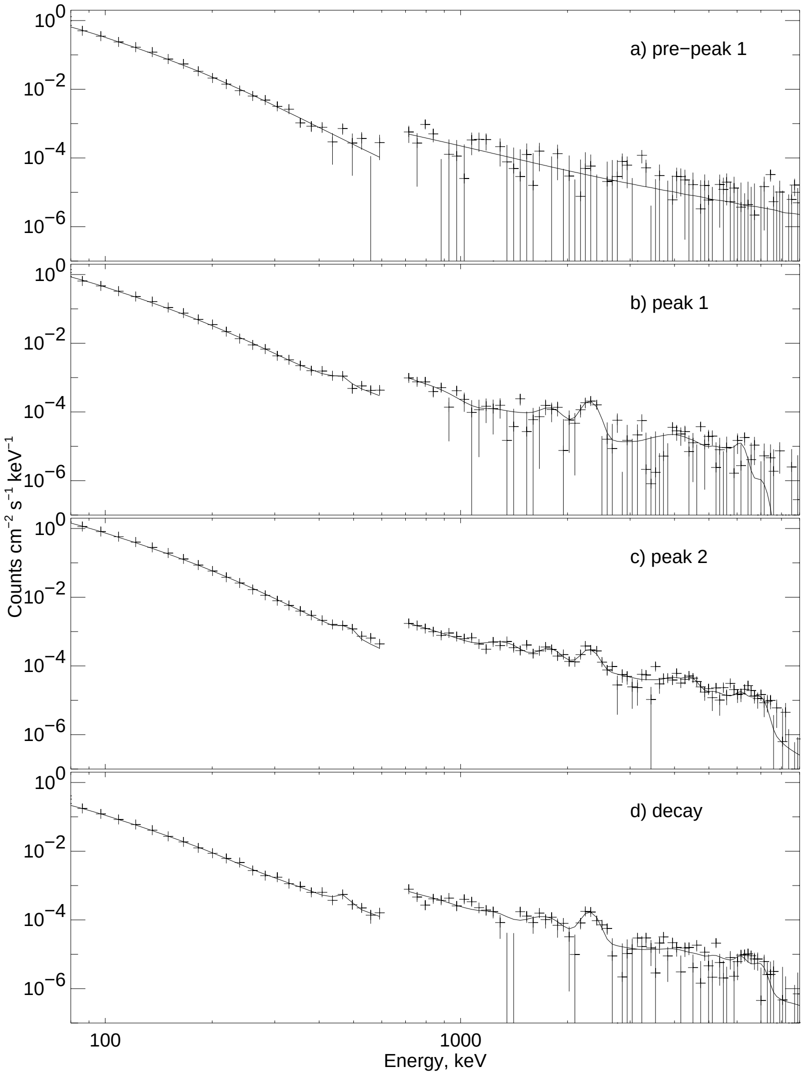

Figure 2. Comparison of counts spectra from the HXS and GRS accumulated from a) 37182 - 37265 s UT, b) 37265 - 37460 s UT, c) 37462 - 37800 s UT, and d) 37800 - 38300 s UT. Solid lines show best fit models. Rates have been divided by the geometrical areas.

the first peak through the decay phase in Figure 3 for both the HXS (60 to 600 keV) and GRS (700 to 9000 keV) detectors. Once again the rates have been divided by the geometric areas of the detectors to enable them to be plotted on the same scale. We used the same forward-folding technique and incident photon models discussed above to fit the data. The nuclear fluence in the $4-7$ MeV band was determined by removing the power-law contribution to the fitted model. Based on these fits we

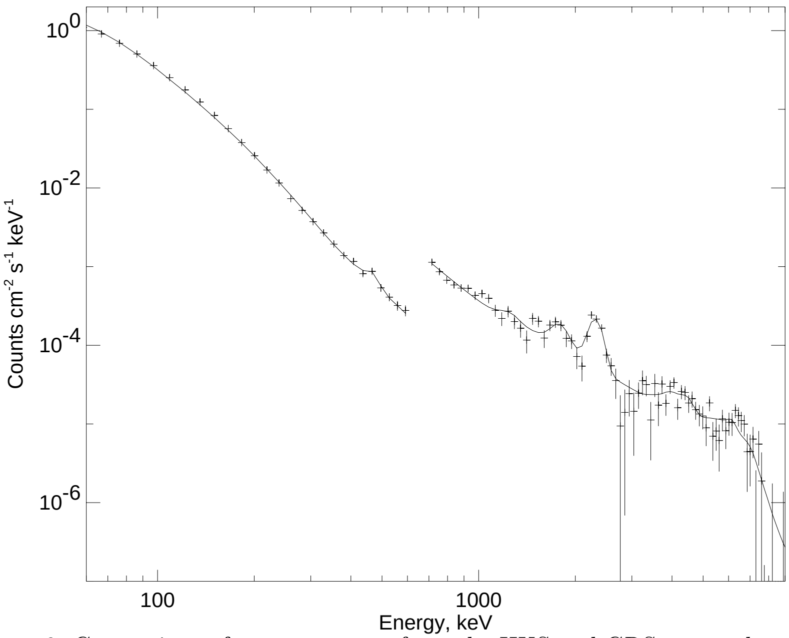

Figure 3. Comparison of counts spectra from the HXS and GRS accumulated from the first peak through the decay phase, 37265 - 38300 s UT. Solid lines show best fit models. Rates have been divided by the geometrical areas.

obtained fluences of 130 $\pm$ 12 and 66 $\pm$ 5 γ cm^{-2} in the 2.223 MeV line and 4 $-$ 7 MeV band, respectively. This yields a 2.2 MeV to 4 $-$ 7 MeV fluence ratio of 1.97 $\pm$ 0.23. All of the spectral uncertainties were determined by mapping the change in χ^2 as the parameter in question was varied, keeping all the other parameters free. The uncertainties are based on $\delta\chi^2$ of 1 (Lampton, Margon, & Bowyer, 1976).

We have used updated Monte Carlo calculations (Ramaty, Kozlovsky, & Murphy 2001, private communication) to obtain the flare-averaged spectrum of accelerated ions assuming an ambient coronal composition with ^{4}He/H =0.1 and an impulsive particle composition (Reames, Meyer, & von Rosenvinge, 1994; Reames, 1995). This yields a power-law proton spectrum with an index of 3.14 $\pm$ 0.15 and 1.1 $\times 10^{32}$ protons MeV^{-1} at 10 MeV. If we assume that this spectrum extends down to 1 MeV/nucleon without hardening and that it is flat below 1 MeV, we obtain 3.5 $\times 10^{29}$ erg in accelerated protons. Assuming the same impulsive particle composition and ions with the same spectral shape, we estimate that there was 1.5 $\times 10^{30}$ erg in accelerated ions. We can compare this with the energy contained in electrons from our fits to the flare-integrated HXS spectrum.

We have fit the flare-integrated spectrum from 60 to 600 keV with a broken power law having the following parameters: flux at 50 keV

$5300 \pm 155\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{keV}^{-1}$; low-energy index 3.70 ± 0.03; break energy $\sim$340 keV; high-energy index 2.7 ± 0.3; 511 keV fluence $31 \pm 10\ \gamma\ \mathrm{cm}^{-2}$. The broken power-law is necessary to fit the data, not only because the spectrum hardens above $\sim$300 keV, but because the fitting algorithm that we have used does not contain a positronium continuum component.

As the hard X-ray and γ-ray fluxes have been obtained from two different instruments we have compared the best fitting photon spectra to determine a relative correction factor. We find that the spectra agree if we multiply the HXS data by a factor of 2 ± 1. We are not certain why this factor is required, but there are indications that it may be dependent on the rate, suggesting inefficiencies in determining live time. Using this factor and the bremsstrahlung spectrum derived above, we estimate that there were 3×10^{32} erg in accelerated electrons above 20 keV (Brown, 1971; Ramaty, et al., 1993). This is about two orders of magnitude higher than that measured in the ions.

We can also compare the corrected annihilation line fluence with the 4 – 7 MeV nuclear fluence to obtain an alternative estimate of the spectral index of the accelerated ions. Based on this ratio we obtain an index of 3.0 (+0.95, −0.25), consistent with what we obtained above.

2.2. Link between hard X-ray hardening in flares and solar-energetic particle events?

Kiplinger (1995) has suggested that the spectral evolution of hard X rays in flares can be used to predict the occurrence of energetic interplanetary proton events. Specifically, his studies with the SMM Hard X-ray Burst Spectrometer indicate that these particle events almost always occur when the spectra of 40 − 200 keV X-rays either harden over flux peaks or during flux decays and seldom occur when such hardening is not observed. The 2000 July 14 flare was associated with the third highest flux of >10 MeV interplanetary protons in the last 25 years. We therefore expect to observe spectral hardening at hard X-ray energies in this flare. Unfortunately, Yohkoh was in the nighttime portion of its orbit during the rise of the flare in soft X rays (Figure 1); any hardening in the hard X rays that may have occurred then was not observable. However, measurements with the HXS and GRS suggest that the most intense portions of the burst likely occurred after the satellite moved into daylight. We have therefore studied this portion of the flare for any evidence of spectral hardening.

We spectroscopically analyzed the HXS data in 50 s intervals after first subtracting background estimated from measurements made after the flare. This background subtraction suffices at these lower energies

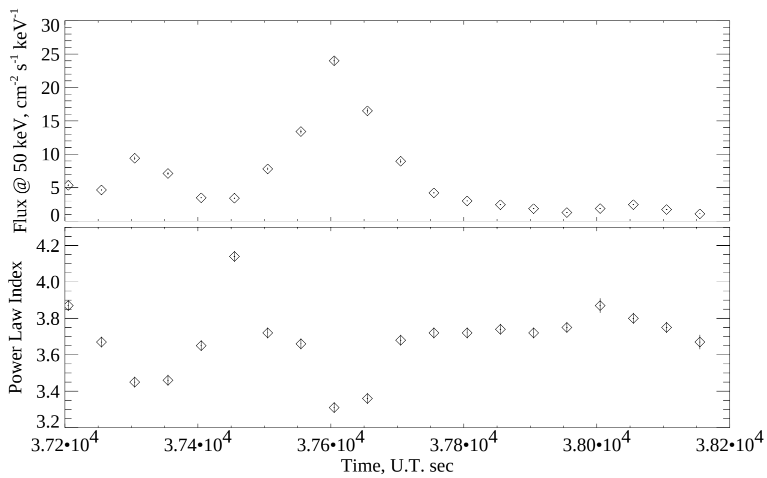

Figure 4. Variation of flux at 50 keV and 50 — 200 keV spectral index

where the flare photons dominate and the background doesn't vary strongly. We then fit the 50 – 200 keV band with a single power law using the χ^2 mapping algorithm discussed above. We plot the measured flux at 50 keV and the index of the power law in Figure 4. The 50 keV flux follows the temporal structure observed in the 100 – 300 keV band plotted in Figure 1. The spectral indices exhibit the traditional 'soft-hard-soft' evolution through the two peaks. They do not exhibit the 'soft-hard-harder' evolution in individual peaks or the gradually hardening spectra through the flare that Kiplinger (1995) found were associated with energetic particle events.

3. Atmospheric Gamma-Rays from the SEP Event

Protons >30 MeV began arriving at Earth at ∼10:35 UT, approximately 8 minutes after the peak in hard X rays and γ rays. The intensities of these particles continued to rise rapidly for the first two hours after the flare. An unrelated CME shock reached earth at about 16:00 UT giving rise to another increase in the particle rates. The rates in particles with energies below about 30 MeV continued to increase for the next 20 hours, while those at higher energies leveled off or began to decline.

The impact of these particles on the Earth's atmosphere was detectable by the HXS and GRS detectors when the satellite reached its

most northerly and southerly excursions ($\pm 31^\circ$ geographic latitude), at magnetic cutoff rigidities near 4 GV. At these locations hard X and γ rays produced in the polar regions by these particles could be detected. The first increases were observed on July 14 at $\sim$12:40 and $\sim$13:30 UT during the rise in SEP intensity at Earth. On later orbits of the day the magnetic rigidities near $\pm 31^\circ$ were too high and the SEP interactions couldn't be observed. The HXS and GRS once again detected fluxes hard X rays and γ rays from SEP interactions at low magnetic rigidity beginning July 15 at 06:10 UT and ending at 13:40 UT. The $1-7$ MeV γ-ray rates varied by a factor of $\sim$2 during this period of maximum SEP intensity.

Because Yohkoh is solar pointed, it is likely that the radiation passed through some amount of spacecraft material before reaching the detectors. The viewing angle of the atmospheric radiation also varies from orbit to orbit. For this reason any flux estimates are likely to be lower limits and there may be differences between the responses of the HXS and GRS. With these caveats in mind, we plotted HXS and GRS count spectra (divided by the geometric areas in the solar direction) during the rise of the event on July 14 and near its peak on July 15 in Figure 5. We subtracted background using data taken at similar geographical locations on earlier days when there was no geomagnetic disturbance. We summed the two July 14 observations because the fluxes were rather weak.

The spectrum accumulated during the peak particle intensity on July 15 is similar to the one observed by the SMM gamma ray spectrometer during the intense 1989 October 20 event (Share & Murphy, 2001). Lines from electron positron annihilation (511 keV), direct excitation of atmospheric ^{14}N (1635 and 2313 keV), and the ^{11}B and ^{12}C spallation products of ^{14}N (4439 and 4444 keV) are resolved in the spectrum. We also observe unresolved lines in the $6-7$ MeV region from N and O. The relative levels of the HXS and GRS responses are similar to that observed for the flare, suggesting once again that we will need to multiply the derived HXS fluxes by about a factor of two (with a 50% uncertainty) in order to make a comparison with the GRS fluxes.

The spectral rates observed from the July 14 observation in Figure 5 are about a factor of ten weaker that those observed on July 15. This is the same factor observed in the >10 MeV particle fluxes observed by GOES and given in Table 1. In order to provide quantitative estimates of the fluxes in the lines, we fit the HXS and GRS spectra over limited ranges ($200-600$ keV in the HXS; $1000-7000$ keV in the GRS) with simple power laws and Gaussians. We plot these fits as solid lines in Figure 5 and have extended them to higher and lower energies for reference.

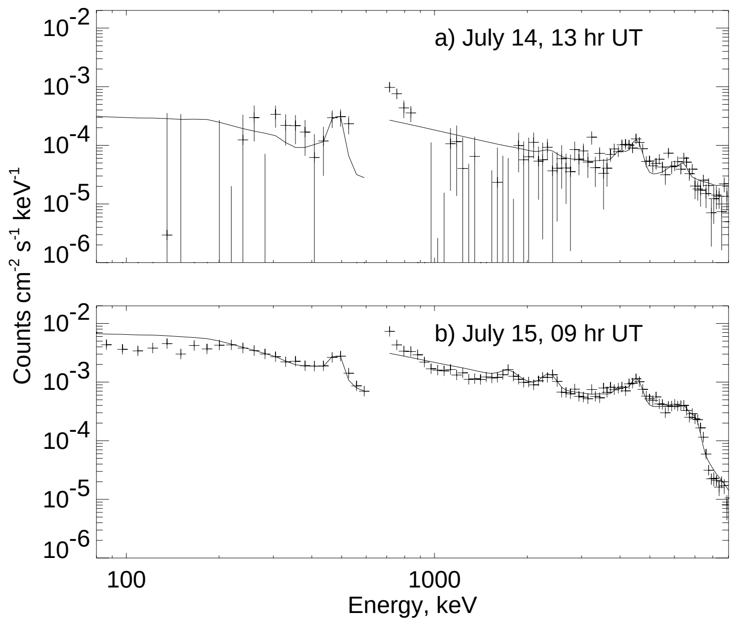

Figure 5. Comparison of count spectra from the HXS and GRS of the Earth's atmosphere during the onset of the particle event on July 14 and near the peak intensity on July 15. Solid lines show best fit models to ranges 200 – 600 keV and 1000 – 7000 keV for the HXS and GRS. Rates have been divided by the geometrical areas.

Table I. GOES Proton Measurements

Date/Time	Flux >10 MeV p $(cm^2\ s\ sr)^{-1}$	Flux Ratios $> 10/ > 30$	$> 30/ > 50$	$> 50/ > 100$
1989 Oct. 20/16 UT	4×10^4	6	3	5.5
2000 July 14/13 UT	2×10^3	1.5	1.5	3
2000 July 15/09 UT	2×10^4	4	3.5	14

We list the resulting line fluxes in Table 2 for the observations on July 14 and 15. For comparison, we also list line fluxes observed by SMM during the 1989 October 20 event (Share & Murphy, 2001) in the Table. The ^{14}N de-excitation line fluxes for the 1989 October event are each a factor of two higher than the respective line fluxes in the 2000 July 15 event. (There may be additional uncertainty in the ratio due to differences in the fields of view of the Yohkoh and SMM spectrometers.) These lines are primarily produced by protons $\geq$ 10 MeV. We find this

Table II. Gamma-Ray Lines from SEP Impact on Earth's Atmosphere

Date/Time	Line Flux (γ cm^{-2}s^{-1})			
	1.63 MeV	2.31 MeV	4.44 MeV	0.511 MeV
1989 October 20/16 UT	0.41 ± 0.02	0.79 ± 0.06	1.00 ± 0.08	1.29 ± 0.01
2000 July 14/13 UT		0.00 ± 0.015	0.10 ± 0.01	0.12 ± 0.04 [0.06]
2000 July 15/09 UT	0.19 ± 0.02	0.40 ± 0.02	0.83 ± 0.03	0.88 ± 0.06 [0.44]

factor of two is the same found in comparing the fluxes of >10 MeV protons listed in Table 1.

The spallation lines at 4.4 MeV are produced by higher energy protons. We note from Table 1 that the July 15 proton spectrum from $\sim$10 − 50 MeV is harder than the spectrum observed on October 20. This harder spectrum appears to be reflected in the significantly higher 4.44/2.31 MeV flux ratio ($\sim$ 2) observed on July 15 compared with what was observed ($\sim$ 1.2) in 1989 (see Table 2). The annihilation line at 0.511 MeV can be produced by even higher-energy protons. As the July 15 proton spectrum softens markedly >50 MeV relative to what was observed on October 20, we would expect the 0.511 MeV/4.44 MeV flux ratio to be higher for the latter. Based only on the statistical errors given in Table 2, this appears to be the case; however, there is an additional systematic error, given in the brackets, due to the uncertainty in the GRS/HXS calibration.

There is no evidence for the 2.3 MeV line from de-excitation of ^{14}N in the July 14 spectrum. The 2σ upper limit is about a factor of three below the flux in the 4.4 MeV line complex. This compares with a measured factor of two for the July 15 observation. This suggests that the 10 − 30 MeV proton spectrum was much harder on July 14. This is consistent with the GOES >10 MeV/>30 MeV flux ratios on those days. The hardness of the proton spectrum at this time is also reflected in the relatively high 511 keV flux (once again the systematic error in the brackets makes this conclusion weaker).

4. Discussion

We have studied several high-energy aspects of the 2000 July 14 solar flare using the Yohkoh Wide Band Spectrometer experiment. In particular we have used the hard X-ray data from the HXS and γ-ray data from the GRS. The observations commenced $\sim$4 m before the peak in soft X-rays and continued for the remainder of the flare. The

flare produced both electron bremsstrahlung and nuclear line emission. The nuclear line emission commenced during the first distinct peak beginning $\sim$37265 s UT. Lines from electron-positron annihilation and neutron capture were clearly distinguished. Because of the moderately poor spectral resolution of the GRS we were not able to separately resolve the narrow and broad de-excitation lines that come from p and α interactions on the ambient solar atmosphere and heavy ion interactions with ambient H and He.

We have obtained nuclear line spectra in four distinct sections of the flare but, because we cannot separately resolve the ^{16}O and ^{20}Ne lines at 6.13 and 1.63 MeV, we are unable to estimate the time varying spectra of flare accelerated ions. However, we have been able to obtain information on the flare-averaged accelerated ion spectrum by using the fluences observed in the 2.223 MeV neutron capture line and in the nuclear radiation contained in the 4 – 7 MeV energy range. For an assumed power law spectrum of accelerated particles, we obtain a spectral index of 3.14 $\pm$ 0.15. Ramaty et al. (1996) determined the spectral indices for 19 intense nuclear line flares observed by the SMM spectrometer (Share & Murphy, 1995). Of these 19 flares only 3 had spectra that were as hard as the July 14 flare. We note that the 1997 November 6 flare, that was also observed by Yohkoh, had an even harder particle spectrum with an index of 2.6 $\pm$ 0.1 (Murphy 2001, priv. communication).

We have estimated the energy content in accelerated ions during the July 14 flare based on these studies. Under the assumption that the power law extends without a break down to 1 MeV, where the spectrum then becomes flat, we estimate that there were 1.5 $\times 10^{30}$ erg in accelerated ions. This compares with our estimate of 3 $\times 10^{32}$ erg in accelerated electrons >20 keV during the flare based on hard X-ray observations with the HXS. Thus the ions comprise at most only $\sim$1 % of the energy in accelerated particles. Ramaty & Mandzhavidze 2000 (Ramaty & Mandzhavidze 2000) have estimated the energy content in ions and electrons in the 19 SMM flares. The energy in ions for these flares ranged from 3 $\times 10^{29}$ to 10^{33} erg. Only 2 of the 19 flares had ion energies less than the July flare. In addition there were no flares in that sample for which the energy in accelerated ions was as small as 1% of the energy in electrons. It is important to note that the study performed by Ramaty & Mandzhavidze 2000 was based on a limited sample of flares that were specifically chosen to have the most intense nuclear line intensities (Share & Murphy, 1995). Thus their conclusion that "the total flare energy in accelerated particles appears to be equipartitioned between $\gtrsim$1 MeV/nucleon ions and $\gtrsim$ 20 keV electrons" may be biased by the selection criterion for the 19 flares.

As the July 14 flare was associated with the third most intense solar energetic proton event >10 MeV event since 1976, it is an excellent candidate to confirm Kiplinger's (1995) premise that spectral hardening in X rays is a reliable predictor of these events. We measured the hard X-ray spectra during 50 s accumulations and found no evidence for 'soft-hard-harder' evolution in individual peaks or gradual hardening through the flare. The failure to confirm this hardening for such an intense SEP is in conflict with Kiplinger's model. However, there remains the remote possibility that such spectral hardening occurred during the early part of the flare, before Yohkoh observations began. Klein, et al. (2001) summarized a broad range of measurements of the 2000 July 14 flare. These include X-ray, EUV, optical, radio, and neutron monitor observations. They suggest that the main phase of energy conversion in the low corona had a maximum near 10:18 UT, about 2 minutes before the Yohkoh observations began. There are no observations to confirm whether the hard X-rays and gamma-rays also peaked at this earlier time. Had there been significant ion acceleration during this time, we would have expected to detect a strong nueutron capture line as soon as Yohkoh began its observations. We did not detect this line until a few minutes later. This suggests that ion acceleration, and the most intense hard X radiation, probably did not commence until the Yohkoh observations began.

The solar energetic particles associated with the flare and CME reached the Earth's atmosphere and interacted to produce γ-ray lines that were observed by Yohkoh at high magnetic latitudes beginning about two hours after the flare. The atmospheric spectrum observed by Yohkoh is similar to that observed by the SMM spectrometer during the intense SEP event on 1989 October 20. The peak intensity in protons >10 MeV during that event was about twice the flux measured on July 15 during the peak of the event, when we made our spectral measurements. The fluxes in the two ^{14}N de-excitation lines that are produced by protons at those energies also differed by the same factor two for these two events. By comparing the intensities in the ^{14}N lines with those in ^{11}B and ^{12}C spallation lines we conclude that the $\sim$10 – 50 MeV particle spectrum interacting with the Earth's atmosphere was harder in the July 15 event than it was in the October 20 event. This is again consistent with the particle measurements in space. The qualitative agreement between the particle spectra in space and those that reach Earth suggests that there are not large transport effects for particles impacting the atmosphere near the magnetic poles.

Although the GRS instrument has degraded in performance since launch, it continues to operate and has provided a 10-year history of hard X-ray and γ-ray flares. Since the loss of the Compton Observatory,

it is the only functioning solar γ-ray instrument. With the forthcoming launch of HESSI (Lin et al., 2000), the WBS will still have an important role in providing complementary data.

Acknowledgements

This work was supported by NASA DPR's S-92690-F and W-18995.

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